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NOTES ON THE DESIGN OF AILERONS.

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Recent data have shown that certain forms or types of ailerons in extensive use, are in reality quite inefficient and entirely unsuited for the high speeds now realized. The same data also show forms B and C on Figure 3 to be efficient and satisfactory in every way.

The most important of the characteristics required of ailerons are:

1. Effectiveness under all conditions of flight;
2. Small moments about the hinge;
3. High efficiency (small yawing moment opposing turn);
4. Simplicity in construction.

The following notes have been compiled from various sources in order to supply data and instructions for obtaining satisfactory results based on the requirements just enumerated.

Chord, or Depth.

Tests conducted at the National Physical Laboratory (British A.C.A..R & M 550 and 615) show that the maximum rolling moment obtained is practically independent of the aileron chord d, provided that d is not less than about 15% of the wing chord c.

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However, the greater the value of d/c, the greater the moments about the hinge, the greater the yawing moments (opposing turn), and the less the rolling moments per unit aileron area. In general, the best results are obtained when d/c is between .20 and .30.

Table I contains comparative figures, taken from test data, showing the variation of rolling moment per unit aileron area with the ratio d/c. In this table the rolling moment for $d/c = .25$ taken as unity. The average values when plotted (Fig. 1), lie on the straight line (1) which has the equation

$$\eta_1 = 1.50 - 2.00\,(d/c) \quad \ldots\ldots\ldots\ldots \quad (1)$$

where η_1 is the ratio of the rolling moment per unit area, at any given aileron setting, for an aileron whose chord is d/c, to that for an aileron whose chord is 25% c (i.e. $d/c = .25$). This equation is used later to determine the variation of aileron area with plan form, retaining constant effectiveness.

Span.

Table II contains comparative rolling moments per unit aileron area for ailerons of various spans, as obtained in the NPL tests. It is quite interesting to compare this experimental data with the values predicted from the assumption that the wing area forward of the aileron is affected uniformly over the entire length of the aileron. That is, the rolling moment due to an aileron will be proportional to the product of the wing area which it affects by the moment of this area about the center of gravity. Table III contains the relative moments per unit aileron area for ailerons of varying length, calculated on this assumption. The calculated values check the experimental values very closely as may be seen from Fig. 1, where the line (2) represents the calculated values and the points marked with circles, the experimental values. The line (2) is defined by the equation

$$\eta_2 = (1.20 - 0.6\ (L/b)\ ) \ldots\ldots\ldots\ldots (2)$$

where L/b is the ratio of aileron span to wing span and η_2 the relative rolling moment per unit aileron area referred to $L/b = 1/3$ as unity. This equation will be used later to determine the variation of aileron area with plan form, retaining constant effectiveness.

The ratio of rolling moment to hinge moment, usually called aileron efficiency, is found to be a maximum when $L/b = 2/3$. For the best average results L/b should be greater than 0.35 and less than 0.70. Very long ailerons are liable to deflect and bind at the hinges.

Area.

For the average airplane the aileron area is about 11% of the wing area. This would correspond to an aileron with $d/c = 1/3$ and $L/b = 1/3$.

These proportions were once in extensive use, although the present tendency is towards narrower ailerons. Assuming that the proportions given are satisfactory, the proportions of a series of ailerons giving the same lateral control may be calculated from equations (1) and (2). The relative effectiveness for depth and length, for the case given, are 0.833 and 1.00 respectively. The relative area is therefore the product of these efficiencies by the actual area or

$$Ae = .111 \times 0.833 = 0.0925$$

The proportions of all ailerons having this effective area are given by

$$L\ (1.20 - 0.6\ L/b) \times d\ (1.50 - d/c) = .0925\ bc \quad . \ . \ . \ . \quad (3)$$

The heavy curve on Fig. 2 is calculated from equation (3). On the same figure are given a number of points marked by crosses, each representing a well known airplane. On the same figure there are also given two inclined lines representing reasonable limits to the aileron area as dependent upon the ratio d/c, which should in turn lie between 0.20 and 0.30 with a recommended average of 0.25.

Several conclusions may be drawn from Fig. 2, the most important being that too much aileron area is used in many cases, particularly with the older designs in which d/c is large. Another conclusion is that there is a well-defined lower limit to the amount of aileron area required for a given degree of lateral control, in this case, corresponding to $d/c = .20$ and $L/b = .50$.

Plan form.

The plan form of the ailerons is partially fixed by the plan form of the wings. Tests have shown that the best results are obtained from a wing tip rounded elliptically or raked with the leading edge longer than the trailing edge. The wing tips should never be raked with the leading edge shorter than the trailing edge for several reasons, the most important of which is the extremely high loading which occurs on the extreme tip of this type of wing. With the ordinary construction this peak in loading comes on the aileron and increases the hinge moments while decreasing the aileron efficiency. Another reason for avoiding the wing tip raked so that the leading edge is shorter than the trailing edge, may be found in the behavior of the general pressure distribution on the wing tip. It is well known that a slight washout in angle of attack towards the tip improves the performance of the wing by preventing the early breakdown in lift which first takes place on the tip, and thus equalizing the loading over the wing. It may easily be seen that the old type of aileron shown as A in Fig. 3, gives an increase in angle towards the tip and that the flow must be seriously disturbed.

The best plan form for an aileron is not as yet definitely determined, although it is known that certain forms such as B and C on Fig. 3, give very good results. These forms are recommended for general use.

The "skew" setting is objectionable when of the form shown in

D in Fig. 3. The full effect of the angular movement is lost and the loading is objectionable. Difficulty is liable to be met with this form of aileron binding when the wing deflects. The hinges of all ailerons should be so arranged as to minimize the effect of any warp or twist in the wing.

General Conclusions.

The following conclusions may be drawn from a study of the references listed elsewhere in this note:

(1) The aileron chord should be about 25% of the wing chord - never more than 33% and never less than 20%. It is recommended that 30% be used as the upper limit.

(2) The aileron span should be greater than 35% of the semi-wing span. With an aileron having $t/c = .25$, the span should be between 40% and 50% of the semi-wing span for normal control when the wing has an aspect ratio of 6.

(3) In the general case the aileron area should vary from 9% to 12% of the wing area as the aileron chord varies from 20% to 35% of the wing chord.

(4) The plan form of the aileron should be such that there is in effect a washout of angle of attack towards the tip - such as that given on a normal aileron on an elliptically rounded wing tip

(5) The aileron should never extend beyond the mean tip of the wing.

(6) All types of skew settings are to be discouraged.

(7) The aileron hinges should be designed to prevent binding if the wing deflects or twists.

(8) Ailerons on high speed airplanes should always be of the forms B or C, or some modification of these forms, and should be made very rigid to prevent vibration.

References:

"Test on RAF-6 Aerofoil with Hinged Rear Margin" - Washington Navy Yard, W.T.R. #34.

"Air Forces and Moments for Loening M-80 Airplane" - Washington Navy Yard, W.T.R. #211.

"An Investigation of the Aerodynamic Properties of Wing Ailerons, Part I - Effect of Variation of Plan Form of Wing Tip and Span of Aileron" - Br. A.C.A. R&M #550.

"An Investigation of the Aerodynamic Properties of Wing Ailerons, Part II - The Effect of Variation of Chord of Aileron, etc." - Br. A.C.A. R&M #550.

"Pressure Distribution over Thick Aerofoils" - N.A.C.A. Report #150.

"Pressure Distribution over Thick Wings Including Ailerons" - N.A.C.A. Report #161.

"Naval Architecture in Aeronautics" (Hunsaker), 1920, July, Aeronautical Journal.

Table I.

Variation of rolling moment per unit aileron area with aileron chord. Comparative values taken from test data - Br. A.C.A. R&M #550, Table 9.

Aileron angle δ	d/c = .167	d/c = .220	$\alpha = 16°$ d/c = .250	d/c = .284	d/c = .350
5	1.29	1.32	-	1.16	1.00
10	1.50	1.36	-	1.16	1.00
15	1.49	1.34	-	1.16	1.00
20	1.41	1.29	-	1.13	1.00
25	1.34	1.19	-	1.18	1.00
Average	1.45	1.32	1.25	1.16	1.00
Comparative average	1.16	1.06	1.00	.93	.80

Table II.

Variation of rolling moment per unit aileron area with aileron span. Comparative values taken from test data - Br. A.C.A. R&M #550, tables 26-28.

Aileron angle δ	$\alpha = 8^{\circ}$ L/b=.333	L/b=.50	L/b=.667	$\alpha = 16^{\circ}$ L/b=.333	L/b=.50	L/b=.667
5	1.00	.95	.91	1.00	.90	.76
10	1.00	.89	.84	1.00	.94	.70
15	1.00	.91	.84	1.00	.96	.77
20	1.00	.91	.81	1.00	.93	.78
25	1.00	.88	.83	1.00	.93	.79
30	1.00	.90	.82	1.00	.93	.80
Average	1.00	.91	.84	1.00	.93	.77
General Average				1.00	.92	.805

Table III.

Variation of aileron effectiveness per unit area with aileron span. Calculated values based on wing area affected.

Aileron span/ Wing span. L/b	Wing area affected. Se/S	Moment arm of area affected. l/b	Moment of area affected $M = \left(\frac{Sex}{S}\frac{l}{b}\right)$	Relative aileron area A_r	Relative moment per unit aileron area M/A_r	Relative efficiency η
.20	.20	.90	.180	.20	.90	1.08
.30	.30	.85	.255	.30	.85	1.02
.333	.333	.833	.278	.333	.833	1.00
.40	.40	.80	.320	.40	.80	.96
.50	.50	.75	.375	.50	.75	.90
.60	.60	.70	.420	.60	.70	.84
.70	.70	.65	.455	.70	.65	.78
.80	.80	.60	.480	.80	.60	.72
.90	.90	.55	.495	.90	.55	.66

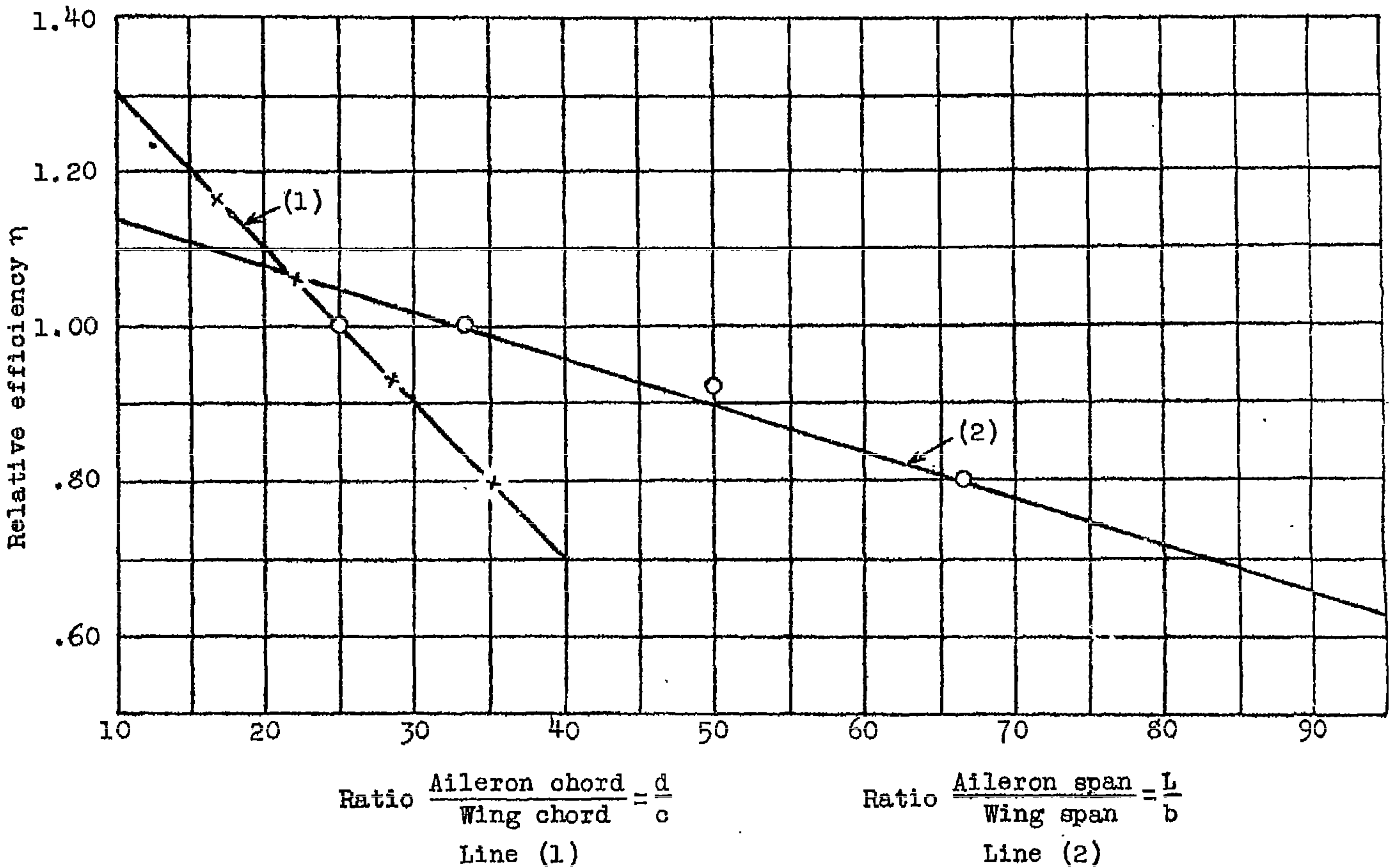
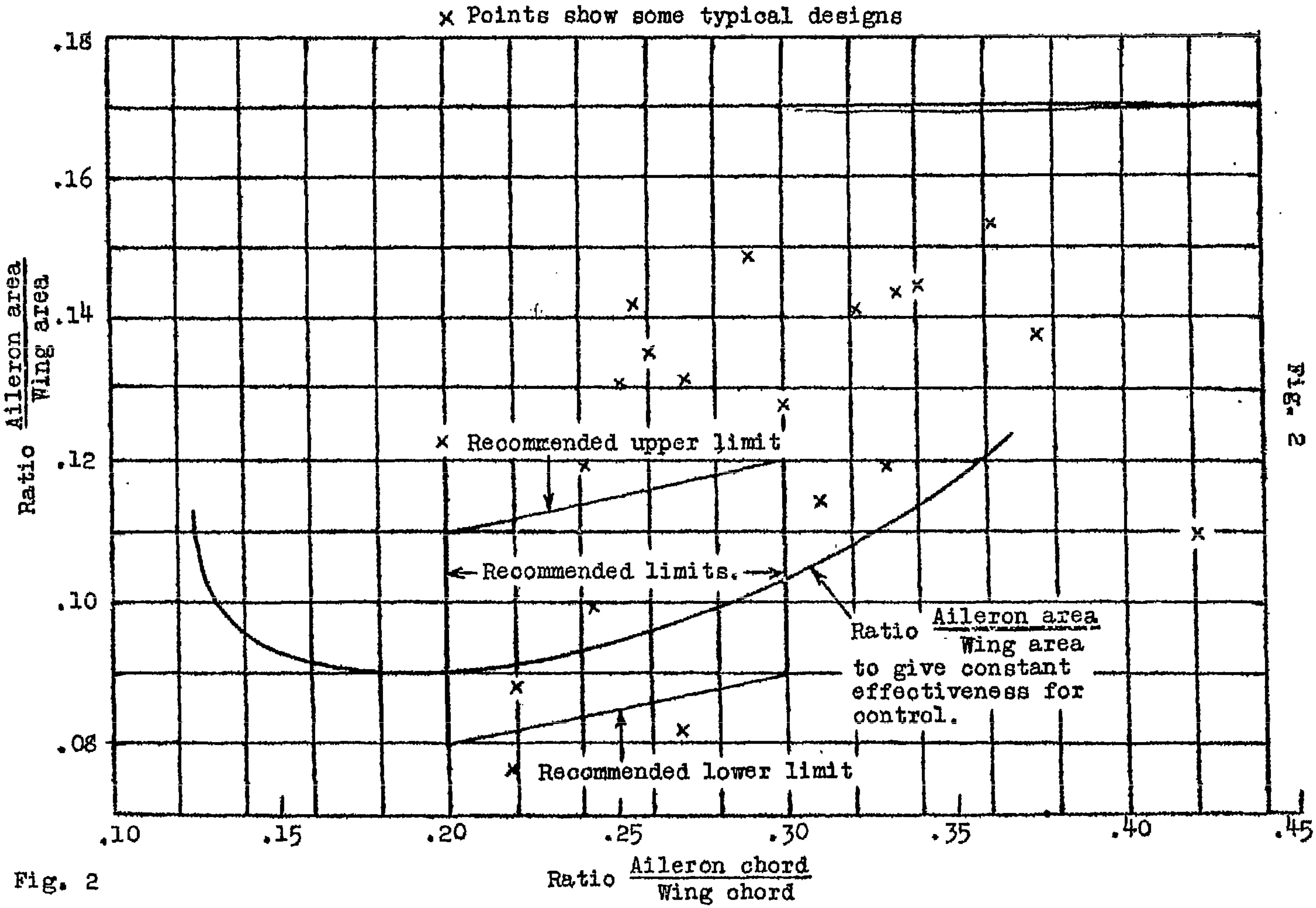


Fig. 1 Relative effectiveness of ailerons of various spans and chords

Fig. 1

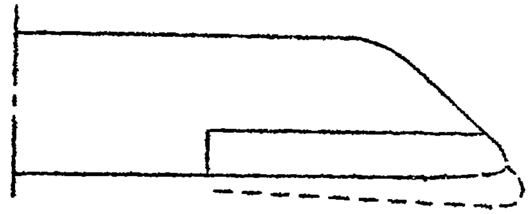


× Points show some typical designs
.18
.16
.14
.12
.10
.08
Ratio Aileron area / Wing area
Recommended upper limit
Recommended limits.
Recommended lower limit
Ratio Aileron area / Wing area to give constant effectiveness for control.
.10
.15
.20
.25
.30
.35
.40
.45
Ratio Aileron chord / Wing chord

Fig. 2

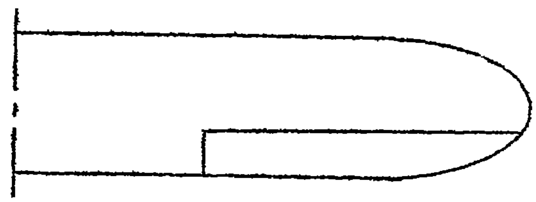
Fig. 3

A



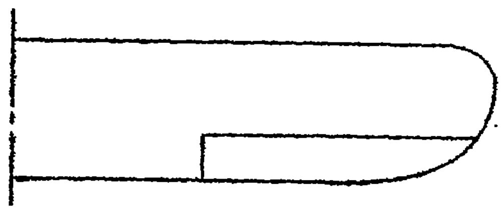
Old type. Inefficient. Form shown with dotted lines is less efficient. Neither form is recommended.

B



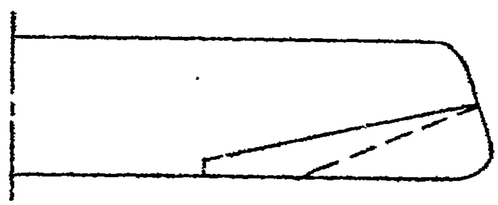
Elliptical tip. Efficient ailerons recommended type. Very good for high speed designs.

C



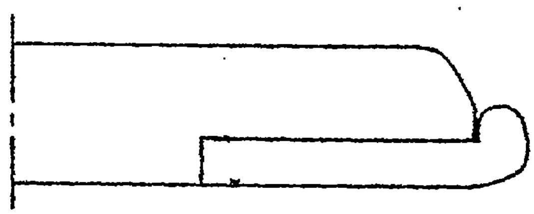
Raked tip. Efficient ailerons recommended type for general use.

D



Raked tip - Skew ailerons Very inefficient. Not to be used.

E



Raked tip with overhung aileron balance. Inefficient. Subject to very high local loading. Not to be used on high speed designs.

Fig. 3 Types of ailerons